Response:

11 Mbps DSSS systems are in production today. It is therefore difficult, if not meaningless, to compare costs of products that are in production to claims made by the proponents of WBFH. There is no evidence to support the claim that WBFH systems capable of reliably delivering high rate data will enjoy any cost advantage.

As described above, support for time bounded services with guaranteed QoS can be servicedby either DSSS or FHSS PHYs. At this time, the IEEE 802.11 Working Group is evaluating extended features for the MAC which will enhance the ability of high rate DSSS radios to service both telephony and multimedia applications.

2.4.2 CUBE Must Substantiate Claims Made to the Commission

CUBE Reply Comments, page 16:

"As long as WBFH will not cause increased levels of interference to other users of the 2.4 GHz band – as Section IV demonstrates – the Commission should let the market assess the relative merits of competing systems."

Response:

WECA agrees the level of interference that authorization of WBFH devices would cause to other users of the 2.4 GHz band is a central issue in this proceeding. However, the overarching issue is whether the proposed rule changes serve the public interest. HomeRF and other proponents of WBFH have repeatedly made claims before the Commission regarding the benefits that consumers would realize if WBFH systems were authorized. It is therefore essential that these claims be substantiated before the Commission acts on them. Reliance on the market for decision-making is inappropriate where the proponents not only have failed to substantiate their public interest claims, but where the market experiment would threaten the operations of a large embedded base of compliant equipment.

2.4.3 CUBE Misrepresents Published Data on Delay Spread (Kamerman)

CUBE Reply Comments, page 17:

"...the maximum delay spread in most office environments is in the range of 40-70 nsec [12], the maximum delay spread in a home environment is substantially lower".

Response:

The following response is provided by Ad Kamerman of Lucent Technologies:

The comments of CUBE are a misrepresentation of the cited reference. That reference [12] provides a literature survey encompassing a variety of environments with median and maximum values. The maximum values for office buildings are between 56 and 150 nsec, not 40-70 nsec as indicated by CUBE. The same document also provides typical values for small office and single room of 19 and 25 ns. (max. 30 ns). However, according to the surveyed articles, these values are based on distances of only 1 to 10 meters. Other studies survey reports on propagation show a wide variety of results on delay spread as can be expected in the 2.4 GHz band.

2.4.4 Intersil Simulations Included Filter Effects

CUBE Reply Comments, page 18:

"The basis of the opponents argument is the response characteristic of the analog discriminator to signals offset from the tank circuit center frequency. Using a combination of oversimplified analysis and measured data on existing FH products, they assert that partially overlapping channels can have signal-to-interference ratios that are up to 7 dB worse than fully overlapping co-channel interference. They further present dire eye diagrams and dramatic tables of results to illustrate serious interference problems. Notably, all of these are made with the channel filtering removed. No one, however, even would consider building a wireless LAN with no channel filtering."

Response:

The foregoing comment is one of many statements that demonstrate CUBE's failure to understand the analysis submitted by Intersil on the issue of partially overlapping FHSS channels. That analysis [1] presented receiver desensitization data for an Aironet IEEE 802.11 FHSS product. The measurements were taken in accordance with procedures specified in the IEEE

802.11 WLAN Standard. Figure 2.0-2 of that report clearly indicated that the FHSS receiver tested was, in fact, 7 dB more sensitive to interference from a partially overlapped interferor. That figure is reproduced below as Figure 2.4.4-1.

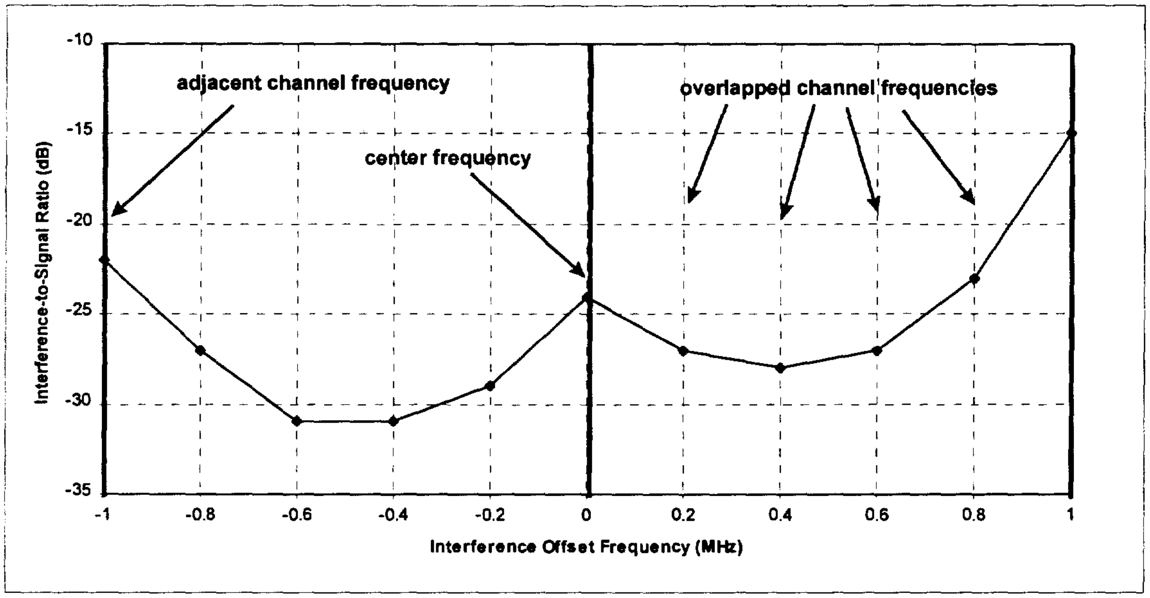

Figure 2.4.4-1 Subset of Rx Desensitization Data (10^{-5} BER Threshold) Demonstrates Interference is Most Severe from Partially Overlapped Channels

Some features of the data shown in Figure 2.4.4-1 are worth mentioning. The device under test is an Aironet 4FSK receiver capable of 2 Mbps. It has very good channel filtering. Note that the receiver is actually less sensitive to interference at offset frequencies of +/- 1 MHz corresponding to a full channel offset (Adjacent Channel Interference, or ACI), than to co-channel interference (CCI). Referring to Table 1 of the CUBE Reply Comments, note that the Proxim OpenAir radio tested is actually *more* sensitive to ACI than CCI. In this manner, the Aironet radio is superior to the Proxim OpenAir radio used by CUBE in its own testing of the effects of interference from offset frequencies.

In order to demonstrate that the effect of interference from offset frequencies is not an implementation-dependent phenomenon, the Intersil analysis included simulations of an FHSS receiver which featured both an idealized discriminator and very effective channel filtering. Channel width and frequency offsets were scaled to simulate operation in a 5 MHz channel. The presence of a channel filter was clearly indicated in Figure 3.3-1 of the Intersil report. Results of the simulation were in excellent agreement with the measured results described above. The results were summarized in Figure 4.0-1 of the Intersil report [1] and are reproduced below as Figure 2.4.4-2.

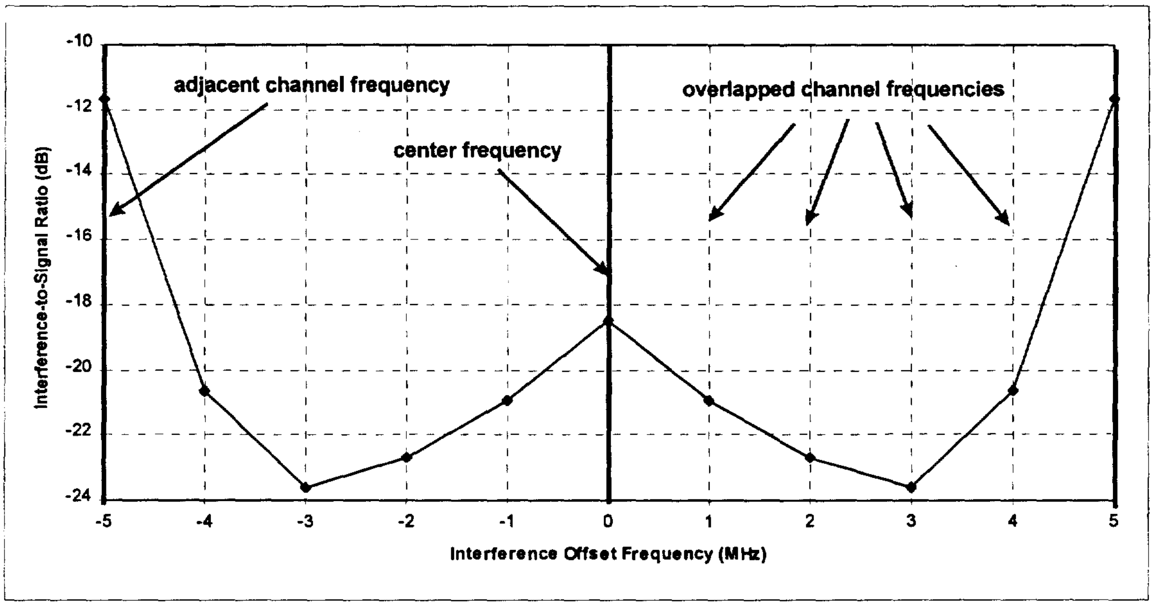

Figure 2.4.4-2 Simulated Rx Desense for Overlapping 5 MHz WBFH Channels (10^{-3} BER Threshold)

Once the effects of offset channels were reproduced in simulation, a closed form mathematical analysis was presented which demonstrated that the effect of interference was proportional to the square of frequency offset. As Equation (6) of the Intersil analysis demonstrated, the effect of interference was, in fact, proportional to the square of frequency offset. As will be described in greater detail in Section (2.8.1), the results shown in Equation (6) are valid even for very low SIR values.

One of the central arguments of the Intersil analysis is that the distinctive "W" shape of the receiver desensitization curve is due to a combination of the aforementioned dependence of frequency offset, and the effect of channel filtering. (For a more detailed description, refer to Section 5.3 of the Intersil analysis [1]). In order to demonstrate that the effect was thoroughly understood, results of a subsequent analysis (which was performed with the channel filter removed) were presented. These results were presented only to demonstrate that a complete understanding of the behavior of the FM demodulator in the presence of interference from partially offset channels was at hand. This was clearly stated on page 15 of the Intersil report: *"In order to demonstrate the validity of this explanation, simulations have been run with the receiver filtering removed and thermal noise eliminated. This enables study of the effect of frequency offset in isolation."*

At no time did Intersil state or imply that the results shown for the simulation which was performed with the channel filtering removed were representative of what would be realized in practice with effective channel filtering installed. Instead, those results were presented solely to further validate the results shown in Figures 2.0-2 and 4.0-1 of the Intersil analysis (reproduced in this document as figures 2.4.4-1 and 2.4.4-2).

2.4.5 CUBE Results Ignore Partially Overlapped Channels

CUBE Reply Comments, page 18:

"Detailed numerical simulations and measurements of products made by CUBE members show that, at most, there will be a 3 dB increase in signal-to-interference ratio due to a partial overlap on a discriminator. The real question, of course, is what effect would 3 dB of increased self-interference – or even 7 dB – if the opponents' dire predictions hold true – have on systems operating with a 100 dB total link budget in real home environments."

Response:

After more than one year after making the proposal to the Commission, proponents of WBFH still have failed to publish any test data or simulations of the effect of partially overlapping FHSS channels. Specifically, there are absolutely no results in the CUBE filing which address the issue of WBFH vs. WBFH interference. The issues of WBFH interference to existing systems, is relevant. However, so is the issue of WBFH performance in the presence of interference from existing systems.

The issue of WBFH susceptibility is of central importance, because a high incidence of retransmissions resulting from packet errors will contribute directly to the level of interference encountered by other users of the spectrum.

The CUBE testing does address the impact of the use of wider FHSS channels on a conventional Proxim OpenAir receiver. However, the level to which wider FHSS channels enhance the effects of interference depends on several variables, which include the modulation index of the desired signal and the selectivity of the receiver channel filtering. Unfortunately, no details or assumptions related to the numerical simulations performed by the CUBE members were included in their reply comments. It is therefore not possible to comment directly on the CUBE simulations.

It is however very noteworthy that CUBE indicates an increase in interference due to partially overlapping channels, regardless of the level. The fact that a 3 or 7 dB increase in interference is small relative to the total link budget is immaterial for two reasons:

1.) The WBFH proposal is different from a previously rejected proposal put forward by Symbol in two ways. The minimum hop rate has been increased, and the minimum number of hopping channels has been held constant. Both of these measures have been shown to actually increase interference. Based on these considerations, the current proposal is technically inferior to the earlier proposal by Symbol, which was rejected.

2.) ***The simple measure of prohibiting the use of overlapping channels can reduce interference among WBFH systems by as much as 50%.*** If overlapping channels are prohibited, those hopping frequencies which would have resulted in partial channel overlap will instead result in either CCI or ACI. Although the net improvement for CCI over partial channel interference is in dispute (3 dB or 7 dB), there will in fact be a net decrease in interference. However, the most substantial improvement will be realized when those channels that would have otherwise resulted in offsets of 3 or 4 MHz are instead remapped to the adjacent non-overlapping channel. For systems employing effective channel filtering (which has been shown to be practical by manufacturers of Bluetooth radios), the effects of ACI can be significantly reduced or eliminated.

To expand on this second point, Bluetooth radios are required to operate reliably with an FHSS interferor with a relative power of 0 dB on the Adjacent Channel. This effectively demonstrates how well an FSK radio can combat ACI, if designed with this characteristic in mind. However, if WBFH were authorized with the use of overlapping channels required, the technology would be hamstrung with a level of interference which no amount of filtering could correct, since the interference would fall within the receiver passband.

2.4.6 HomeRF Results were Based on Unrealistic Assumptions

CUBE Reply Comments, page 19:

"The answer to this question [the effects of overlapped channels] is apparent from the extensive simulation work of the HomeRF Technical Committee, which was presented to the Commission prior to issuance of the NPRM. The HomeRF Group analyzed the effects of partially overlapping channels on WBFH devices while making far more pessimistic assumptions than this miniscule 3 dB discriminator effect. To be conservative, the HomeRF Technical Committee assumed both a uniform distribution of energy in the WBFH transmit channel and that interfering networks would be active at the 5 MHz hopping channel width 100% of the time.

Despite the use of these highly pessimistic assumptions (which dwarf the 3 dB discriminator effect), the HomeRF group found that throughput degradation for detached family homes with 5 MHz WBFH systems in both the target home and all surrounding homes in the neighborhood was essentially zero."

Response:

WECA has carefully reviewed the presentation made to the FCC by the HomeRF Technical Committee prior to issuance of the NPRM [4]. Contrary to the statements of CUBE, many assumptions made by HomeRF were extremely optimistic. Specifically:

1.) The analysis assumes ideal channel filtering. As a result, ACI (channels offset by 5 MHz from the desired signal) is absolutely zero.
2.) The analysis is based strictly on 2FSK modulation, transmitting data at 5 Mbps (half the peak data rate claimed by proponents).
3.) The uniform interference energy density assumed in the passband of the desired signal (in the event of an overlap) is in fact an average density which corresponds to 55% (5/9) of the interference energy which would be encountered in the event of a

co-channel overlap. While this assumption may facilitate analysis, it is very simplistic and can in no way be considered to be conservative.

4.) The most indefensible assumptions involve the user scenarios which HomeRF analyzed. The user scenarios either involved multiple cells at close range, separated by barriers which provided a "step" attenuation for the interfering signal, or open offices with adjacent cells separated by 30 meters. It should be noted that even with cell separations of 30 meters, WBFH performance began to degrade due to interference at a range of just 10 meters from the Access Point.

Although CUBE and HomeRF may be envisioning applications restricted to home use, the proposed rule changes will be more broadly applicable. In addition, the propagation model assumed by HomeRF for the analysis is more severe than free space losses, and is a reasonable approximation for the types of losses encountered for indoor propagation. Therefore, it already accounts for additional losses due to the types of obstructions encountered in indoor applications, including walls. Given the varied construction techniques used in homes and apartments, the "step" attenuation between the interference source and central network is an extremely arbitrary assumption.

In order to demonstrate the degree to which the HomeRF results rested upon unrealistic assumptions, WECA has reproduced the results of the HomeRF spreadsheet analysis of the Multi-Family Dwelling Scenario based on the following assumptions:

NBYTES	= 500
Np	= 6
Rp	= 15
Pp	= 20 dBm
Pc	= 20 dBm

The results of the WECA spreadsheet analysis are shown in Figure 2.4.6-1. The curve designated as *"2FSK (5Mbps) Step"* indicates the estimated level of interference under the assumptions employed by the HomeRF Technical Committee. In order to show the dramatic effect associated with two of the HomeRF assumptions, WECA repeated the spreadsheet simulation under the same conditions, with the exception that the aforementioned "step" attenuation of 12 dB for the peripheral interfering network is removed. These results are reflected in the curve labeled *"2FSK (5 Mbps) No Step"*. Note the remarkable difference in the predicted levels of interference.

As mentioned previously, the proponents of WBFH have made virtually no mention of the performance of the system while delivering the claimed data rate of 10 Mbps. In order to show the effects of interference, the spreadsheet simulation was repeated again with the 12 dB "Step" attenuation for the interfering networks removed, and with the desired signal of the central network being transmitted at 10 Mbps using 4FSK modulation. The results are even more dramatic. The 4FSK system delivering the claimed data rate of 10 Mbps begins to suffer from the effects of interference at ranges as short as 2 meters even though it is transmitting 100 mW. Further, throughput for the 4FSK system drops precipitously at 13 meters because the received signal is too weak to ensure reliable demodulation. This result does not even begin to take into account the effects of signal fading due to multipath.

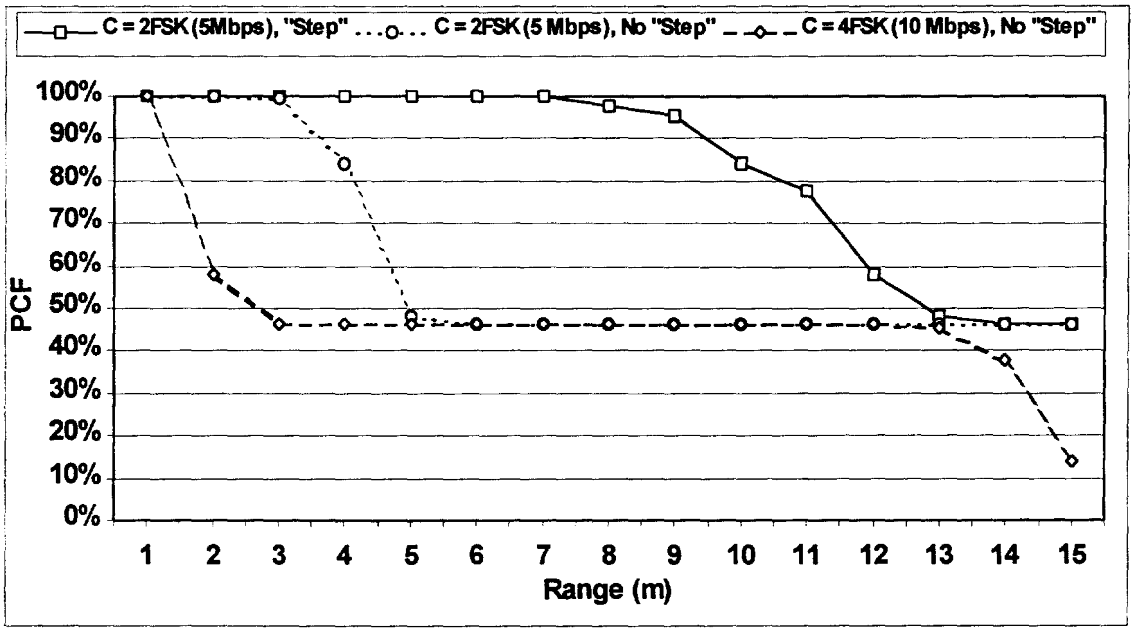

Figure 2.4.6-1 Analysis of WBFH Interference Effects Using Modified Assumptions

Note that the foregoing spreadsheet analysis is identical to the one performed by the HomeRF Technical Committee. The only modifications are those which were performed to demonstrate the impact of some of the more arbitrary assumptions used by HomeRF in their earlier presentation to OET. These modifications were limited to the removal of the "Step" attenuation for the interference sources, and analysis of the effects of interference from peripheral networks on 4FSK modulation operating at 10 Mbps. The results shown above would suffer further degradation if the effects of non-ideal filter selectivity, signal fading due to multipath, or a more realistic noise distribution were included in the model.

2.4.7 WBFH Claims of Interference Immunity are Inflated

CUBE Reply Comments, page 20:

"A 1 MHz wide FH system is 40 times more likely to encounter a very narrowband interferer than is a 25 kHz wide FH system, which is permitted at 2.4 GHz under the existing rules. And a 22 MHz wide null-null bandwidth IEEE 802.11b DS device is a further 20 times more susceptible than the FH device. Note that the 10 dB interference rejection in channel is insignificant compared to the 40 dB or more rejection out of channel."

Response:

The above comment of CUBE is based on the assumption that the bandwidth of susceptibilty of a conventional FHSS receiver to narrowband interference is 1 MHz. In fact, CUBE's own test data clearly demonstrates that the Proxim OpenAir product used for testing purposes has a bandwidth of susceptibility of at least 3 MHz. Referring to Table 1 on page 35 of the CUBE Reply Comments, it is clear that the OpenAir radio is actually more susceptible to CW jammer adjacent channel interference than co-channel interference. This is also true if the interference source is another FH radio. The DSSS system is therefore about 7 times more likely to encounter a narrowband interferor, not 20 times as stated by CUBE.

The degree of interference immunity is not based solely on relative bandwidth of susceptibility to interference. There are three requirements which must be met for a digital radio to encounter interference:

1.) the interference must overlap the radio transmission in time
2.) the interference must fall within the receiver passband
3.) the interference must have sufficient power to result in bit errors.

These three statements are fairly obvious, but in fact they are often overlooked when discussing the issue of interference immunity. Although a conventional FHSS system is about 7 times less likely to encounter a narrowband jammer, FHSS systems are more susceptible to interference when it does fall in-band. Due to a combination of processing gain and efficient DPSK modulation, DSSS radios are 15 to 20 dB (30 to 100 times) more tolerant of interference which falls in band.

It would be extremely difficult to build a WBFH system which has a bandwidth of susceptibility to narrowband interference which is less than 7 MHz (5 MHz channel width + 1 MHz guard band on either side of the receiver passband). This is evidenced by the data shown in Table 1 of the CUBE Reply Comments. This data indicates that the Proxim OpenAir radio having a 1 MHz channel width is actually more susceptible to narrowband interference which is centered at +/-1 MHz relative to the receiver passband.

It is therefore reasonable to assume that a WBFH radio is about 3 times less likely to encounter a narrowband interferor. However, WBFH systems can be effectively jammed by a signal which is 10 to 20 dB (10 to 100 times) weaker than the level which would be required to disrupt a high rate DSSS system. In short, DSSS systems will encounter narrowband interference more often than conventional FHSS systems operating at the same data rate, but DSSS systems are far more able to suppress in-band interference than are FHSS systems.

2.4.8 Proposed WBFH Radios will be Unreliable

CUBE Reply Comments, page 21:

"For the HomeRF system, the current receiver channel bandwidth is approximately 1.3 MHz, while the proposed 10 Mb/s "5 MHz" system would use approximately 3.5 MHz – a ratio of less than 3, not 5, in bandwidth difference due to additional transmit filtering."

Response:

The HomeRF implementation is based on the OpenAir radio platform. It uses a wide channel filter so that other critical radio parameters, such as local oscillator offset, can be relaxed, thereby reducing the cost of the radio. The problem with this approach is that the relatively wide channel filter renders the radio more susceptible to adjacent channel interference. As shown in Table 1 of the CUBE reply comments, the OpenAir radio is actually more susceptible to ACI from either a CW tone or another FHSS interference source.

Similarly, a low cost WBFH implementation could be expected to use wide channel filtering to permit relaxation of key radio parameters. This is particularly true for 4FSK radios, which can tolerate very little group delay across the receiver passband. Wide filters with flat amplitude response and constant group delay are essential for reliable demodulation of the 4FSK waveform. However, these same wider filters render the radio more susceptible to ACI.

The bandwidth over which a WBFH radio is susceptible to interference will very likely be significantly wider than the signal bandwidth. For example, the existing OpenAir radio has a 1 MHz signal bandwidth, but is susceptible to interference over a 3 MHz wide band.

Finally, HomeRF's use of a narrower bandwidth of 3.5 MHz for their 10 Mbps radio may actually increase the susceptibility of the radio to interference, and will likely render it extremely unreliable even in the absence of interference. As indicated on page 27 of the CUBE reply comments, the 10 Mbps HomeRF radio will indeed use a 4FSK waveform. However, reducing the transmitted bandwidth to 3.5 MHz (-20 dB relative to peak) will require reductions in the modulation index (h), the effective bandwidth of the transmitter pulse shaping filter (BT), or both. These measures will result in performance for WBFH that is actually worse than that of the 4FSK radio (h = 0.15, BT = 0.5) used in the WECA analysis.

2.4.9 WBFH Rules Changes will Not be Restricted to Consumer Applications

CUBE Reply Comments, page 22:

"Most consumers are going to use at most one 2.4 GHz broadband wireless network to link many devices. If they select a HomeRF system, they will be able to use one coordinated network, without self interference, to combine their Internet access, cordless telephony, and streaming audio and video needs."

Response:

The proposed WBFH rule changes will not be restricted in their application to the home. Further, CUBE's assertion that there will be only one type of wireless networking device in the home is purely speculative, and will very likely prove to be wrong. Bluetooth radios are expected to be installed in nearly every new cell phone and portable computer, as well as many peripheral devices, within the next couple of years. Bluetooth is expected to become as ubiquitous as InfraRed ports are today. Therefore, the issue of interference cannot be dismissed by assuming that all of the 2.4 GHz devices found in the home can be coordinated via a central network.

2.5 CUBE Section III: Industry Support

Section III of the CUBE filing deals with the issue of industry support. It does not deal directly with the technical issues at hand, and therefore is beyond the scope of this technical rebuttal. It is entirely fitting that the Commission solicit and carefully evaluate industry opinion when evaluating proposed regulatory changes. The final decision must be supported by technical analysis made on the record during the course of this proceeding. The comments of CUBE notwithstanding, the record indicates a lack of consensus on key technical points.

2.6 CUBE Section IV: Interference

2.6.1 WBFH Radios Result in Higher Interference to Other Users

Cube Reply Comments, page 28:

"The second obvious point is that the opponents' assertion that WBFH will occupy three or five "channels" at a time is completely false. WBFH occupies multiple 1 MHz slices of the spectrum on an instantaneous basis in worst case at about the same extent as existing FH systems and, generally, much less, especially for the peak center 1 MHz channel where the interference potential is greatest."

Response:

WBFH systems will, in fact, interfere with other systems over a much wider bandwidth than existing FH systems. This fact is demonstrated by both Intersil's analysis and CUBE's test data. Again referring to Table 1 of the CUBE reply comments, it can be seen that when the WBFH system is used as a jammer, the resulting interference levels are 16 to 23 dB higher for a channel offset of +/- 2 MHz as compared to the case where a conventional 802.11 FH radio is used. For channel offsets of +/- 3 MHz the difference is more than 20 dB. The CUBE test data is summarized in Table 2.6.1 below.

Note that even for CCI, the OpenAir radio is more sensitive to WBFH interference than than to interference from a conventional narrowband FHSS radio. On the surface, this would appear to be somewhat paradoxical, given that much of the WBFH interference power lies outside the passband of the OpenAir receiver. However, this effect was predicted in the Intersil analysis of the effects of WBFH interference on Bluetooth radios [6].

The WBFH signal in question does not use the full 5 MHz channel width proposed. The WBFH signal only has a 3.5 MHz channel width. The relative interference numbers stated above would be even worse if a system with a full 5 MHz transmit bandwidth were to be used as an interference source.

Channel Offset	**IEEE 802.11 FH (SIR, dBm)**	**WBFH (as measured) (SIR, dBm)**	**Delta (dB)**
-3	<-30	-8	>22
-2	-18	5	23
-1	15	18	3
0	14	18	4
1	15	18	3
2	-11	5	16
3	<-30	-7	>23

Figure 2.6.1-1 Summary of CUBE Test Data (Receiver Desense Effects of WBFH)

2.6.2 DSSS Radios Provide Greater Range at Much Lower Transmit Power

CUBE Reply Comments, page 29:

For example, the vast majority of OpenAir products sold by Proxim – a company that alone sells more than 50% of all 2.4 GHz WLANs – and all of Proxim's IEEE 802.11 FH compliant products leave the factory in a nominal +27 dBm configuration for the US and other "FCC countries".

Response:

In contrast to the power levels used by Proxim's OpenAir radios, the vast majority of Direct Sequence WLAN radios sold today have transmit power levels of 50 mW or less. WECA knows of no DSSS radio sold for indoor use which exceeds 100 mW transmit power. The higher values of EIRP for DSSS systems described by CUBE are solely for outdoor point-to-point applications.

In spite of the use of lower transmit power, these radios have ranges which are superior to OpenAir radios that operate at nearly ten times the transmit power. DSSS radios use efficient modulation (DQPSK) to transmit high rate data. To illustrate this point, compare an FHSS radio transmitting 2 Mbps using 4FSK modulation with a DSSS radio transmitting 2 Mbps using DQPSK modulation. Referring to the BER curve of Figure 2.1.1-1, for a BER of 10^{-5}, the DSSS system requires an Eb/No of 12 dB, while the FHSS system would require about 24 dB. The required SNR for each system can be computed by:

$$SNR = Eb/No \times R/B$$

Where: R = data rate (bits/sec)
B = signal bandwidth

For a DSSS radio, the post-correlation bandwidth (2 MHz) is used to determine noise floor. The respective SNR for each system is shown in Table 2.1.16-1.

Radio Type	**Modulation**	**Data Rate (Mbps)**	**Eb/No (BER = 10^{-5})**	**SNR (BER = 10^{-5})**
DSSS	DQPSK	2.0	12	12
FHSS	4FSK	2.0	24	27

Table 2.6.2-1 Comparison of SNR for 10^{-5} BER

As indicated in Table 2.6.2-1, the DSSS system enjoys an advantage of 15 dB relative to the FHSS system operating at 2.0 Mbps. These results are completely scaleable to a comparison of WBFH and IEEE 802.11B systems operating at 10 Mbps. As a result of the superior efficiency of DQPSK modulation, the DSSS system can more than overcome the difference in transmit power. At 2 Mbps, the DSSS system transmitting just 50 mW will have a greater operating range than an FHSS system transmitting 500 mW.

DSSS radios employ efficient modulation methods and increasingly sophisticated baseband processing methods to reduce transmit power requirements. These measures are important to reduce power consumption for portable applications, as well as for reduction of clutter in the band. In contrast, the high SNR levels required for reliable demodulation of 4FSK signals will force WBFH radios to transmit at or near the maximum allowable power of 200 mW to serve the envisioned applications over even a very short range. At the same time, WBFH systems will be capable of interfering with other users of the 2.4 GHz ISM band at a much longer distance. This does not constitute efficient use of the spectrum.

2.6.3 Hop Rate Issue is Resolved

CUBE Reply Comments, page 30:

"Several commenting parties argued that increasing the hop rate for WBFH systems will not reduce the interference threat to other users of the 2.4 GHz band and, therefore, that the Commission should not mandate higher hop rates. While CUBE does not endorse the opponents' position, it believes the central issue is the maximum power versus 20 dBc channel bandwidth, not the hop rate. CUBE therefore does not oppose leaving the hopping channel carrier occupancy regulations unchanged from the existing 2.5 hops/s (or 0.4 hopping channel carrier occupancy per any 30 sec period)."

Response:

WECA applauds CUBE's decision to drop pursuit of increasing the mandatory minimum hop rate for WBFH radios.

2.6.4 Increasing Hop Rate Increases Interference to Other Users

CUBE Reply Comments, page 30:

"Hopping faster has the advantage of spending less time on an instantaneous basis at a channel that may be experiencing interference, which is generally seen as good."

Response:

The above comment typifies the oversimplified and largely incorrect arguments which CUBE has made in support of WBFH. As described in the Intersil analysis of the effects of increasing hop rates [3], the shorter duration of interference or channel fading which results from increasing the hop rate can only be regarded as a favorable by the faster hopping system itself. Even then, as CUBE has noted, the increased hop rate comes at the expense of decreased throughput. This result is desirable only for applications in which latency is more important than throughput.

All other systems which might encounter the effects of interference from an FHSS system with an increased hop rate will suffer an increased collision rate and reduced throughput *regardless of their application.*

2.6.5 Increased Hop Rate Increases Frequency of Collisions

CUBE Reply Comments, page 31:

"For target systems concerned about latency, faster hopping interferers are preferred because they get off a given channel faster."

Response:

Such descriptions of the positive benefits of faster hopping rates to target systems necessarily rely on heuristic arguments and are wrong. From the perspective of a target system, any objective analysis will clearly demonstrate that increasing the hop rate of the interfering system will increase the frequency of interference encountered by the target system. Even intermittent interference will corrupt packets, regardless of whether those packets contain data or digitized voice. Therefore, faster hopping interferers do not benefit target systems which service applications in which latency is a critical factor.

2.6.6 Wide IF Filter of OpenAir Radio Distorts CUBE Test Results

CUBE Reply Comments, page 33:

"For example, Intersil's analysis suggests a 10 dB worse signal-to-interference response for WBFH-on-legacy-FH versus legacy-FH-on-legacy-FH for the case of adjacent channel overlap. CUBE's numerical simulations and detailed measurements all show only a 3 dB effect

in this case at equal transmit power and, naturally, up to 4 dB less for WBFH when the transmit power restrictions are considered."

Response:

The Intersil results are correct and have been independently confirmed by simulation and measurements performed by Silicon Wave [16]. The differences in the results reported by CUBE and the simulations performed by Intersil and Silicon Wave are explained by the difference in channel filtering between a Proxim OpenAir radio and a Bluetooth radio. The Intersil analysis was based on the impact of WBFH interference on a Bluetooth receiver. Bluetooth receivers have excellent channel filtering and ACI rejection characteristics, as demonstrated by the data of Table 2.1.20-1. The CUBE measurements were taken with an OpenAir radio as the target receiver, which uses a much wider IF filter.

Channel Offset	Bluetooth (minimum specs)	Open Air (measured results)
CCI	11 dB	14 dB
+/- 1 ch	0 dB	15 dB
+/- 2 ch	- 30 dB	-11 dB
+/- 3 ch	- 40 dB	-28 dB
+/- 4 ch	- 40 dB	> -30 dB

Table 2.6.6-1 Comparison of Interference Rejection Characteristics of Bluetooth and OpenAir Radios

Table 2.6.6-1 compares the interference rejection specification for a Bluetooth radio to the measured results for an OpenAir radio as reported by CUBE. This parameter quantifies the minimum degree that the two radio types must be able to reject interference from other narrowband FHSS radios operating on neighboring channels.

The Bluetooth radio can reject interference of equal strength (0 dB) from another Bluetooth transmitter which is operating on the adjacent channel (offset of +/-1 channel). Note that the OpenAir radio is actually MORE sensitive to interference on the adjacent channel (15 dB) than on the co-channel (14 dB). The OpenAir radio fails to meet the Bluetooth minimum

ACI requirement by 15 dB. At a separation of +/- 2 channels, the OpenAir radio fails to meet the Bluetooth interference rejection requirement by nearly 20 dB!

The reason that the CUBE measurements indicate only a 3 dB difference between the interference response for WBFH-on-legacy-FH versus legacy-FH-on-legacy-FH for the case of adjacent channel overlap is due to the fact that the OpenAir radio has no adjacent channel rejection capability. In fact, as already mentioned, the OpenAir radio is actually *more* sensitive to ACI than to CCI. Since the OpenAir radio does not effectively suppress ACI, its performance is only marginally degraded when the adjacent channel narrowband interferor is replaced by a WBFH interference source.

The Intersil simulations were performed with a channel filter which was tight enough to ensure compliance with the Bluetooth interference rejection requirements. The Bluetooth receiver does a good job of rejecting a narrowband interferer on the adjacent channel. However, when a WBFH interference source is centered on the adjacent channel, the interference spills into the Bluetooth receiver passband. The Bluetooth receiver performance is consequently seriously degraded, as predicted by the Intersil simulations.

In summary, the differences between the Intersil simulation results and the test results reported by CUBE are due to differences in the devices under investigation, and are not due to inaccuracies in the Intersil simulations. If a target receiver having good interference rejection would have been used for testing, CUBE would have produced results far more in line with the Intersil simulations.

2.6.7 CUBE Representation of Effects of Power Reduction is Misleading

CUBE Reply Comments, page 35:

"Detailed measurements of signal-to-interference ratios for an existing FH device subjected to interferers at various channel-center-to-channel-center offsets are summarized in Appendix 3. The results are shown in Table 1. The WBFH results are presented both on an as-measured basis and an effective basis, where the substantial power reductions imposed by the Commission's proposal are factored into the relative comparisons in the table."

Response:

In Table 1 of the CUBE comments, there are two columns showing test results for interference inflicted on an OpenAir radio from a WBFH transmitter. The levels shown for *"WBFH (effective)"* are misleading and should be ignored by the Commission. SIR is defined as the Signal-to-Interference Ratio *measured at the receiver input.*

Changing the transmit power will not alter the performance of the receiver for a given SIR. All other things being equal, lowering the transmitted power from an interference source will increase the SIR at the receiver. It will not result in improved receiver performance at a lower SIR.

Consider the case in which a WBFH transmitter is on the same center channel as an OpenAir network. From the data in Table 1 of the CUBE Reply Comments, the data in the column labeled *"WBFH (effective)"* indicates that the OpenAir receiver would operate reliably at an SIR of >11 dB. This is not the case. An SIR of 18 dB is required at the receiver regardless of the power level of the WBFH transmitter. The issue of maximum allowable transmit power level for the proposed WBFH transmitters is relevant to this proceeding. However, in order to avoid confusion, it should not be combined with a discussion of receiver performance vs. SIR in this manner.

2.6.8 WBFH Explicitly Forbidden by Existing Regulations

CUBE Reply Comments, page 40:

"Opponents of WBFH misstate the Commission's historical treatment of overlapping channels in a misguided attempt to undermine the validity of WBFH. Intersil states that the Commission has "explicitly forbidden" partially overlapping FH channels and the Commission did so based on "sound engineering practice." However, such usage has been permitted by US military systems over the past five decades to increase capacity and interference immunity, and has been acknowledged publicly for nearly 25 years."

Response:

The specific Intersil comment described above made reference to both ETSI regulations as well as FCC regulations pertaining to FHSS rules:

"Overlapping channels are explicitly forbidden by both European Telecommunications Standards Institute (ETSI) and current FCC rules (15.247) pertaining to FHSS systems operating in the 2.4 GHz ISM band. This prohibition against the use of overlapping channels is based on sound engineering practice."

WECA stands by the accuracy of the above statement, the basis of which can be found in Section 5.1.1 (FHSS Modulation) of ETSI 300 328, and Section 15.247 (a)(1) of the Commission's Rules. Section 5.1.1 of ETSI 300 328 states:

"FHSS modulation shall make use of 20 well defined, non-overlapping channels or hopping positions separated by the channel bandwidth as measured at 20 dB below peak power."

Section 15.247 (a)(1) of the Commission's Rules states:

"Frequency hopping systems shall have hopping channel carrier frequencies separated by a minimum of 25 kHz or the 20 dB bandwidth of the hopping channel, whichever is greater."

Regarding the use of overlapping frequencies for military systems, it is safe to say that these applications have many requirements which are vastly different from those of low cost commercial systems. The design parameters of military systems vary widely, and include hybrid systems which employ both frequency hopping and direct sequence techniques to combat eavesdropping and to enhance reliability in a hostile jamming environment.

Using overlapping channels increases the number of center frequencies employed, thereby making interception of transmitted voice and data by means of eavesdropping more difficult. This is a different matter than increasing throughput and minimizing interference among friendly users of the spectrum in a military application. Unless the specific operating parameters of the systems in question are analyzed in detail, broad statements regarding the use of overlapping channels in military hardware are of no substance, and should be disregarded by the Commission.

2.6.9 No IEEE802.11 Hybrid Systems Built or Type Accepted

CUBE Reply Comments, page 41:

"These figures and the accompanying text show that the IEEE 802.11b contains as part of its approved specification a mode where not only do the approximately 10 MHz wide channels partially overlap, but they also hop at rates consistent with backwards compatibility to IEEE 802.11 FH (up to 50 hops/sec), and at transmit powers up to 1W."

Response:

The above comment describes an optional mode of operation. It is not part of the mandatory operating requirements for IEEE 802.11b products. WECA does not test or certify radios which operate in this mode. To the knowledge of WECA, no such radio has ever been built or submitted to the FCC for type acceptance. If such a radio were submitted for type acceptance, it would have to comply with the Commission's rules as currently written.

2.7 CUBE Section V: Public Interest

2.7.1 Overlapping Channels not Based on Interference Reduction

CUBE Reply Comments, page 42:

"Because WBFH devices can follow existing hopping channel sequences, it is straightforward for manufacturers to build WBFH access points that support the "old" 1 MHz only clients and the "new" dual bandwidth clients simultaneously. Therefore, existing users do not have to replace their existing equipment – now worth billions of dollars – if they choose to upgrade to an existing network"

Response:

The comment above clearly demonstrates that the use of overlapping channels is not driven by interference reduction considerations, but rather by issues of backward compatibility with existing devices. However, even this logic is flawed. CUBE has repeatedly made references to WBFH for home and consumer applications. There is virtually no installed base in the consumer space at this time. Indeed, HomeRF has no products on the market at this time.

The record will clearly indicate that the use of overlapping channels radically increases interference in the band. This explains why the use of overlapping channels has been prohibited for FHSS systems by both ETSI and current FCC regulations.

2.7.2 WBFH Supporters Have Not Substantiated Data Rate Claims

CUBE Reply Comments, page 44:

"The HomeRF Working Group proposes to use 5 MHz of channel width to support 10 Mbps, or 2 b/s/Hz."

Response:

The proponents of WBFH have repeatedly made claim to data rates of up to 10 Mbps in a 5 MHz wide channel. However, there is absolutely no supporting data in the record of this proceeding which indicates that such data rates can be realized in a practical manner. The Eb/No vs BER curve of Figure 2.1.1-1 of this document shows the inefficiency associated the use of 4 FSK signaling, which would be required to achieve the data rates claimed by CUBE. Further, use of such signaling across a broad channel involves even more complexity than manufacturers of narrowband FHSS radios must deal with currently, including more severe channel impairments due to multipath.

2.7.3 WBFH Rules Do Not Comply with ETSI Regulations

CUBE Reply Comments, page 45:

"Today, the approximately 4 MHz wide channel bandwidth as described by the HomeRF Working Group is authorized under ETSI Rules, without any reduction in power from a 1 MHz only FH system, or an IEEE 802.11b system (all are constrained to +20 dBm max)".

Response:

While the 4 MHz wide channel of the HomeRF system would comply with ETSI regulations, the use of overlapping channels would not. ETSI regulations call for a minimum of twenty non-overlapping channels within the band. Further, a WBFH system which used a maximum permissible channel width of 5 MHz would be disallowed. Finally, as pointed out by CUBE, the proposed maximum power levels of WBFH systems (330 mW for 3 MHz channels and 200 mW for 5 MHz channels) would also be disallowed under ETSI rules.

In summary, WBFH radios do not comply with the bandwidth restrictions, channel usage requirements, or transmit power level restrictions of ETSI regulations. CUBE's claim that WBFH represents a step toward regulatory harmonization is therefore indefensible.

2.8 CUBE Appendix 2: Analytical Comments

2.8.1 Discriminator Response Not Dependent on High SIR or Input Noise PSD

CUBE Reply Comments, page A2-1:

Misapplication of the Theoretical Basis: *The equations are taken out of context and are not applicable in many places within documents submitted by Intersil Corporation. For example, an equation was shown that states that the noise spectral density at the output of an FM demodulator is proportional to the square of the frequency offset. In extracting this equation from the textbook derivation (and it appears in numerous references), two significant assumptions were ignored:*

i.) *The equation was derived specifically for the case of band-limited white noise; as Stremler [7] states, "...if one assumes a white noise spectral density for the discriminator input, the output noise spectral density will be parabolic."*

ii.) *Resulting "signal-to-noise" ratios are only valid for the case where the desired signal is much, much larger than the "noise" signal. As stated in the same reference [8] used by Intersil, "[the equation for output SNR] is valid only if the discriminator input SNR is sufficiently large to result in operation above threshold."*

In other words, the squared magnitude response results from a specific set of assumptions that are not valid in this case; analytical results are difficult to derive in low SNR or SIR (signal to interference ratio) cases because of threshold effects. As Stremler [7] states, "Because this [threshold] effect occurs when the noise and signal levels are comparable, it is more difficult to analyze than the high signal-to-noise case."

Response:

The above comment of CUBE is wrong. The discriminator response (in proportion to the square of interference frequency offset) does not depend on either a high SIR ratio or on a white noise spectral density at the discriminator input. Separate responses to both issues are presented in the following paragraphs.

2.8.1.1 Discriminator Response Does Not Depend on a Large SIR

There are two main issues to be dealt with on this point. First, the specific equation cited by CUBE is not applicable to the issue at hand. CUBE is confusing the issue of output SNR with output noise PSD. Secondly, both Stremler [7] and Ziemer & Tranter [8] treat the issue of noise analysis at the output of an FM discriminator in essentially the same manner. In the course of their discussion of this topic, the mathematical analysis is simplified by the assumption of a large SIR. However, it will be shown in this section that the same result can be derived *without* assuming a large SNR, though the mathematics involved is a bit more cumbersome.

CUBE makes reference to Equation (6.126) on page 422 of Ziemer & Tranter [8]. That equation appears below:

$$(\mathrm{SNR})_{\mathrm{DF}} = \frac{3}{4}\left(\frac{B_T}{W}\right)^2 \overline{m_n^{\,2}} \left(\frac{P_T}{N_0 W}\right)$$

As indicated by CUBE, the above equation computes discriminator output SNR, not discriminator output noise spectra (note that all terms are constants, and none are functions of frequency). This equation was not referenced by Intersil and appears to have little or nothing to do with the issue of discriminator output PSD. Instead, this equation shows the effect of changing the modulation index on discriminator output SNR.

The issue of direct relevance is whether the output noise power at the discriminator output is proportional to the square of frequency offset for a narrowband interference source. In Stremler's discussion of this issue, the resulting instantaneous frequency error is characterized by analyzing the rotation of the interference vector (I) relative to the signal vector (S).

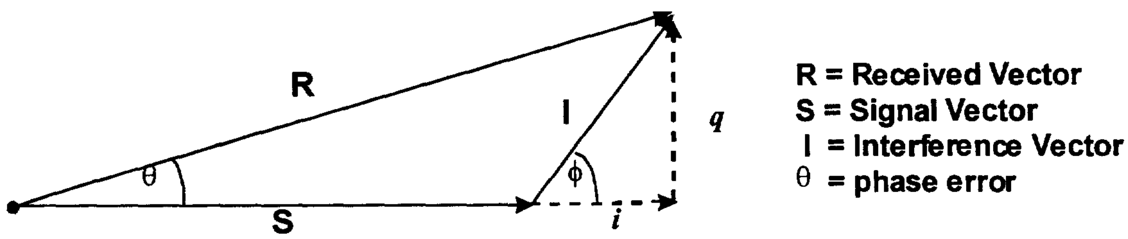

Figure 2.8.1.1-1 Phasor Diagram of Signal and Interference (see Fig. 6-27, Stremler)

The rate of rotation of interference vector (I) relative to signal vector (S) is equal to frequency offset (Δf) between desired signal and interference:

$$\omega = 2\pi\Delta f$$

$$i = I\cos(\omega t)$$

$$q = I\sin(\omega t)$$

$$\phi = \omega t$$

In order to facilitate analysis, vector amplitudes are normalized to the amplitude of the interference vector (I). In this manner, signal vector (S) is expressed in terms of S/I, or Signal-to-Interference Ratio (Σ):

$$I = 1.0$$

$$S = S/I = \Sigma \qquad \text{(where } \Sigma = \text{SIR)}$$

$$i = \cos(\omega t)$$

$$q = \sin(\omega t)$$

$$\theta = \text{instantaneous phase error}$$

$d\theta/dt$ = instantaneous frequency error

From Figure 2.8.1.1-1:

$$phase\ error = \theta = \tan^{-1}\left[\frac{q}{\Sigma + i}\right] = \tan^{-1}\left[\frac{\sin(\omega t)}{\Sigma + \cos(\omega t)}\right] \qquad 2.8.1.1\text{-}(1)$$

The expression for phase error was shown as Equation (6) of the Intersil analysis [1] and is completely analogous to Equation 6.103 in Stremler. In Stremler's approach, a large SIR is assumed. By doing so, Stremler drops the in-phase component (i) of the interference vector (I) to facilitate the rest of his analysis (see Equation 6.104 in Stremler [7]). However, note that the in-phase component is not dropped in the Intersil analysis. Therefore, there is no need to assume a large SIR.

Phase error is dependent on instantaneous phase (ωt) and SIR (Σ). Frequency error ($d\theta/dt$) is the time derivative of phase error (θ). The expression for phase error can be differentiated in closed form. The resulting derivative was shown as Equation (6) in the Intersil analysis. The actual derivation is a bit cumbersome, and was not shown in the original report. In order to demonstrate that the result shown in the Intersil analysis is not dependent on a large SIR, the entire derivation is shown below. In this case, the derivative can be arrived at via application of the chain rule and quotient rule, as follows:

The general form of the derivative of the arctangent function can be found in many math references (e.g. CRC Manual):

$$D_t \tan^{-1}(t) = \frac{1}{1+t^2}$$

Chain Rule: *for* $h(t) = k(g(t)) \Rightarrow h'(t) = k'(g(t))g'(t)$

Quotient Rule: $\dfrac{d}{dx}\left(\dfrac{u}{v}\right) = \dfrac{vu' - uv'}{v^2}$

Therefore,

$$k(t) = tan^{-1}(t)$$

$$g(t) = \left[\frac{\sin(\omega t)}{\Sigma + \cos(\omega t)}\right]$$

Find $g'(t)$:

$$\frac{d}{dt}\left[\frac{\sin(\omega t)}{\Sigma + \cos(\omega t)}\right] = \frac{[\Sigma + \cos(\omega t)]\omega\cos(\omega t) + [\sin(\omega t)\,\omega\sin(\omega t)]}{\Sigma^2 + 2\Sigma\cos(\omega t) + \cos^2(\omega t)}$$

$$= \frac{\Sigma\omega\cos(\omega t) + \omega\cos^2(\omega t) + \omega\sin^2(\omega t)}{\Sigma^2 + 2\Sigma\cos(\omega t) + \cos^2(\omega t)}$$

$$= \frac{\omega(\Sigma\cos(\omega t) + 1)}{\Sigma^2 + 2\Sigma\cos(\omega t) + \cos^2(\omega t)}$$

Solve for instantaneous frequency error ($d\theta/dt$),

$$\frac{d\theta}{dt} = \frac{\dfrac{\omega(\Sigma\cos(\omega t) + 1)}{\Sigma^2 + 2\Sigma\cos(\omega t) + \cos^2(\omega t)}}{1 + \dfrac{\sin^2(\omega t)}{\Sigma^2 + 2\Sigma\cos(\omega t) + \cos^2(\omega t)}}$$

$$= \frac{\omega(\Sigma\cos(\omega t) + 1)}{\Sigma^2 + 2\Sigma\cos(\omega t) + \cos^2(\omega t) + \sin^2(\omega t)}$$

$$= \left[\frac{\omega\left(\Sigma\cos(\omega t) + 1\right)}{\Sigma^2 + 2\Sigma\cos(\omega t) + 1}\right]$$

Therefore, we have finally found the expression for frequency error:

$$\textit{frequency error} \;=\; d\theta/dt \;=\; \left[\frac{\omega\left(\Sigma\cos(\omega t)+1\right)}{\Sigma^2+2\Sigma\cos(\omega t)+1}\right] \quad \text{(see [1], Eq. 6)}$$

Note that the final expression did not rely on assuming a large SIR. In fact, the result contains SIR as a parameter. The above derivation required a lot of algebraic manipulations. Therefore, it's best to check the result numerically. This can be done by evaluating the expression for phase error at two closely spaced points in time and taking the slope. The slope can then be compared the result of the expression for frequency error when evaluated at one of the two points in time. The error can, of course, be made arbitrarily small by making the separation between the two points in time very small.

Consider the case in which the interfering signal (I) is separated in frequency from the desired signal (S) by 0.5 MHz. Let's assume the SIR is just +1 dB. Therefore, with time units in usec and frequency expressed in MHz:

$$\Delta t = 0.00001 \text{ usec}$$

$$\Delta f = 0.5$$

$$\omega = 2\,\pi\,\Delta f = 3.14159\ldots$$

$$\Sigma = 1.122$$

The results of the simple numerical verification described above are shown in Table 2.8.1.1-1. The verification was performed for $0 \leq t < 2$ usec, thereby checking the expression over a range of $0 \leq \omega < 2\pi$.

t_1	t_2	$\theta(t_1)$	$\theta(t_2)$	*slope (numerical)*	*$d\theta/dt$ (closed form)*	% error
0	0.00001	0.0000	0.0000	1.48188	1.481883	0.0000%
0.4	0.40001	0.5872	0.5872	1.43518	1.435179	0.0001%
0.8	0.80001	1.0842	1.0842	0.66707	0.667113	0.0063%
1.2	1.20001	-1.0842	-1.0842	0.66716	0.667113	-0.0063%
1.6	1.60001	-0.5872	-0.5872	1.43518	1.435179	-0.0001%
2	2.00001	0.0000	0.0000	1.48188	1.481883	0.0000%

Table 2.8.1.1-1 Numerical Verification of Frequency Error Calculation (SIR = 1 dB)

Note that the numerical analysis is in excellent agreement with the closed form expression. Therefore, the frequency error is directly dependent on offset frequency (w) even for very small SIR. By extension, the interference voltage at the discriminator output will be directly proportional to offset frequency, and interference output power is proportional to the square of offset frequency, even for small SIR.

As stated above, this method is based on describing the instantaneous phase error relative to the desired signal. Another method of analyzing this issue involves a two-tone analysis. Although this method approaches the issue of the effects of interference at the input to an FM discriminator in a different manner, the conclusion is the same. A complete description of this method is shown in Section 2.8.1.3.

2.8.1.2 Discriminator Response Does Not Depend on Input Noise PSD

Stremler's treatment of this topic describes the dependence of noise power (S_{no}) at the discriminator output on the frequency difference (ω) between the instantaneous frequency of the noise and the carrier frequency. The discriminator output noise is dependent on the square of frequency offset, as shown in Equation 6.107 of Stremler's book:

$$S_{no}(\omega) = \frac{1}{A}\,\omega^2\,S_{ns}(\omega) \qquad \text{(Stremler 6.107)}$$